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Some Trial Computations of Dynamic Instability

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Purpose and Scope

J. Bjerknes, in his Compendium article, advances the theory that frontogenesis is favored, and that cyclogenisis is likely, when conditions in an area meet the requirements of dynamic instability. Such a criterion, if both necessary and sufficient, would be invaluable in the short range prediction of deepening cyclones. It is the purpose of this investigation to test this theory in its simplest form. Specifically, this will correlate anticyclonic shear of the magnitude of the Coriolis parameter, as measured in an isentropic surface[1], with intensification of surface cyclones.

Methods

In the simplest case we shall consider straight-line flow with no accelerations and motion as dry adiabatic. For this type of flow, the condition for dynamic instability is that $\frac{\partial V}{\partial \xi} > f$ with $\partial V / \partial \xi$ measured along an isentrope. To select the ξ axis that would maximise $\partial V / \partial \xi$ was a problem. The most desirable choice would be an axis normal to the isotachs in the region of an isotach maximum, and also upward along the isentropic surface in the region of maximum slope of the surface. As a compromise to these conditions, vertical cross-sections were prepared along axes approximately normal to the surface front and extending for 200 to 400 miles either side of the front. When these axes gave no shear greater than the Coriolis parameter, alternate axes were chosen as a check.

The values of potential temperature and wind speed normal to the axis of the cross-section were obtained from surface and constant pressure charts and were plotted for all standard pressure surfaces to 300 mb for points spaced a distance apart approximately equal to 2 degrees of latitude. The frontal intersection with the surface chart was the approximate center of the cross-section.

An analysis was made of the isentropic and velocity fields. It was then possible to measure directly the anticyclonic shear along an isentrope at all points in the cross-section. This shear divided by the distance between the points was compared with the Coriolis parameter. A value for the shear equal to the Coriolis parameter and approximately valid in all parts of the United States is 10 knots per 0.5 degree of latitude. If this value was obtained in any portion of the chart, it was necessary to forecast the cyclone to intensify and verify the test on subsequent surface charts. In the event there was no indication of dynamic instability and the low did deepen, the charts were reviewed and another cross-section prepared to see if a different choice of the point of examination would have shown dynamic instability. This was

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[1] The isentropic surface was chosen in preference to one of constant pressure because an instability parameter should be measured in the surface that coincides with the axis of minimum stability. The isentropic surface generally approximates such a surface more closely than a constant pressure surface.

to insure against a choice of axis influencing the result.

Examination of Data

The computation was made for four storms occurring in the central United States during October and November 1951. For three of these storms the computation was made after the succession of surface events was known.

For the computation of October 30, cross-sections were selected from the 0330Z surface map with one normal to the warm front and one normal to the cold front of the low on the So. Dakota-Nebraska border (see Table 1 for details of all cross-sections). A small area of shear greater than the critical value selected was noticed at about 400 mbs on the warm front cross-section. In the cold front cross-section, a large area of shear greater than the critical value was found between 800 and 500 mbs. As the intensification criteria is met, deepening should be forecast. Strong deepening occurred in the next 24 hours.

Another computation was made from the data of October 27. The first cross-sections were prepared normal to the front, causing them to intersect in Nebraska. These showed no area where critical anticyclonic shear was approached. As a check, an examination was made along other axes. These were about normal to the flow aloft and ran N-S, but there was no increase in the shear in the upper levels. In the section through the cold front, however, an area was found south of the active front, but behind the Pacific impulse, where the isentropes are nearly vertical. It is unusual to think of anticyclonic shear in a vertical surface and it is felt that this condition of vertical isentropes must be more a measure of thermal instability than of dynamic instability. If, then, this area is not considered, the criterion is not met and one would not forecast cyclogenesis or surface deepening. As indicated on the surface chart 24 hours later, the cyclone did not develop.

The situation of October 6 concerns a low in Arkansas and it has a small area, on the cross-section through the warm front, where critical anticyclonic shear is found. The isotach analysis is rather unusual in this area, and how much credence to give this computation is a problem. In the section through the cold front, we can find no evidence of dynamic instability. Another cross-section was prepared a few degrees farther west along the cold front. In this section it is again impossible to find any area where the shear is near the magnitude of the Coriolis parameter. The forecast to be made from this computation is difficult, but, because of the marked difference between the magnitude of the shear in this case and that of the two previous cases, one should probably forecast no development of the low. The low, however, was a major storm on the following day.

The one case where the computation was made before the surface events were known occurred with a low on the Texas-New Mexico border on November 5th. The first cross-sections did not show any area where the criterion was met. There was a small area behind the cold front where the analysis showed the anticyclonic shear to be of the right magnitude between 800 and 750 mbs, but, since the analysis was not rigid in this area, it was not considered. Twenty-four hours later there had been no deepening of the surface low. Twelve hours after the first examination, however, another test was made and dynamic instability was noticed. Again the cross-section through the warm front had a small area of instability near the 300 mb level and the section through the cold front had an extensive area between 800 and 700 mbs.

According to the testing method, the cyclone would now be forecast to intensify and twenty-four hours later this was indeed the case.

Evaluation of Results and Conclusions

Verification of four of the five forecasts made in this test using the criterion that the low would develop if the anticyclonic shear in an isentropic surface near the low was greater than, or approximated the Coriolis parameter, and the converse, would indicate that further development of the theory would be valuable. It is possible that a more intensive study of the case that failed would give proper modification to the criterion.

The test should also be expanded to include the general case where curvature and accelerations are considered and moist adiabatic motion is assumed in rain and cloud areas.

An interesting observation is that in none of the areas where dynamic instability was indicated along an isentrope would the measurement along a constant pressure surface have given a value equal to the Coriolis parameter. If this measurement is indeed an important limit, then it is clear that the measurement should be made in an isentropic surface.

Table 1

Details of Cross-sections

Date of Cross-section	Type of Front	Coordinates of End Points of Cross-section Axes	Normal to Front?	Size and Location of area of Critical Shear	Deepening Fcst	Deepening Verify
October 30 1951 03Z	Warm	96°W; 40–50°N	Yes	Small area around 400 mbs at about 46°N.	Yes	Yes
	Cold	106°W; 37–47°N	Yes	Large area 800–500mbs north of 44°N		
October 27 1951 03Z	Stat.	41°N, 101°W–31°N, 92°W	Yes	None	No	No
		41°N, 101°W–32°N, 110°W	Yes	None		
		95°W; 32–42°N	No	None		
		105°W; 32–42°N	No	None		
October 6 1951 15Z	Warm	88°W; 32–42°N	Approx.	Very small at 500mbs & 36°N	No	Yes
	Cold	97°W; 28–38°N	No	None		
	Cold	26°N; 98°W–38°N, 102°W	Approx.	None		
November 5 1951 03Z	Stat.	37°N; 93°W–29°N, 101°W	No	None	No	No
		41°N, 101°W–36°N, 112°W	No	None		
November 5 1951 15Z	Warm	92°W; 28–39°N	Yes	Small area at 300 mb about 33N	Yes	Yes
	Cold	102°W; 29–40°N	Yes	Large area between 800 & 700 mbs from 35°N to 40°N		